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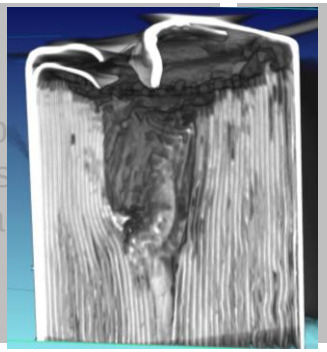

Developing Battery Safety and Abuse Testing for Stationary Battery Applications

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Energy Storage Peer Review

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U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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Approach and Capabilities

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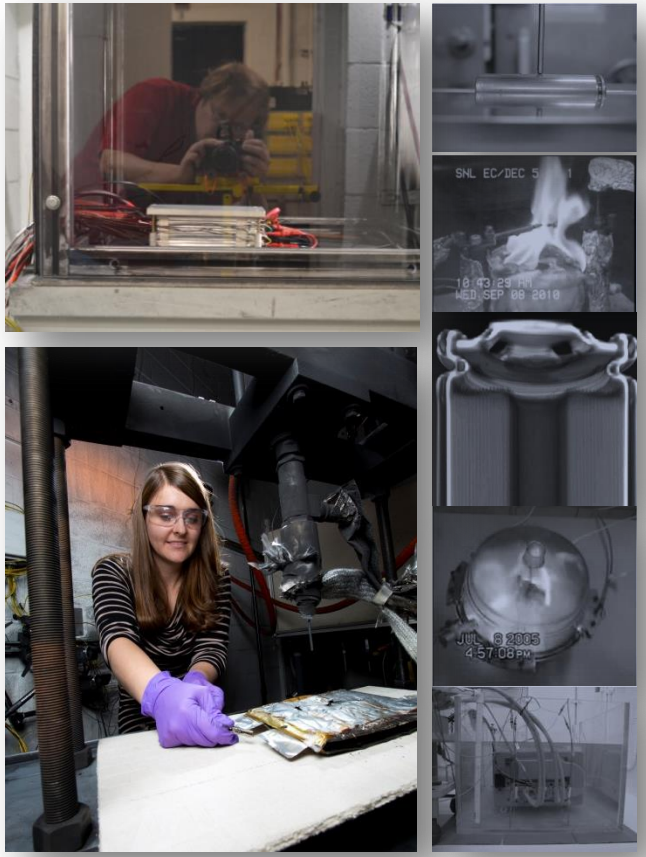
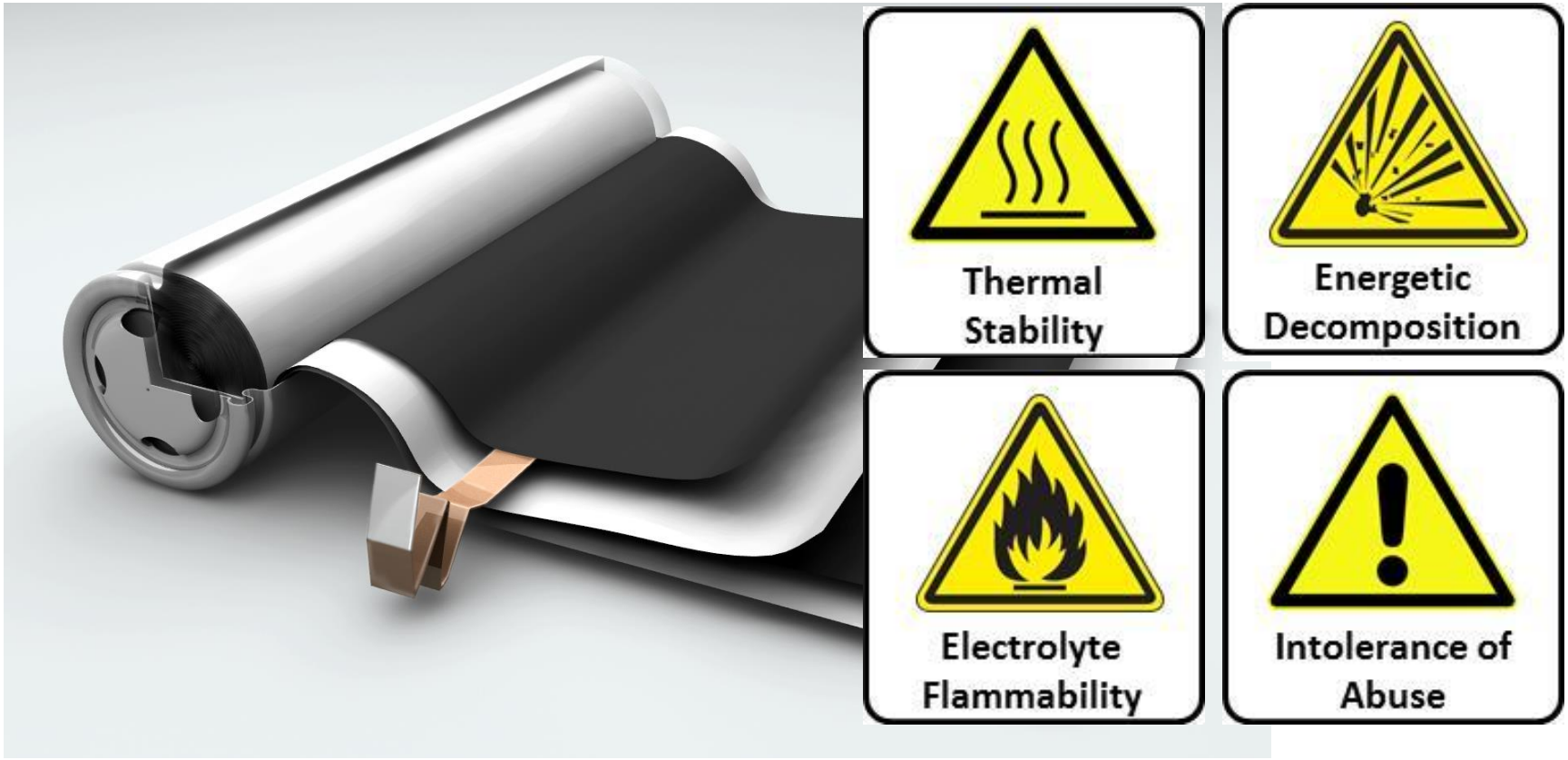
Cell and Module Testing
Battery Abuse Testing Laboratory (BATLab)



Battery Pack/System Testing
Thermal Test Complex (TTC) and Burnsite

Battery Calorimetry

Lithium-ion Safety Issues



Testing program aimed at understanding and improving abuse tolerance of energy storage systems

Discharge of cells under abuse conditions

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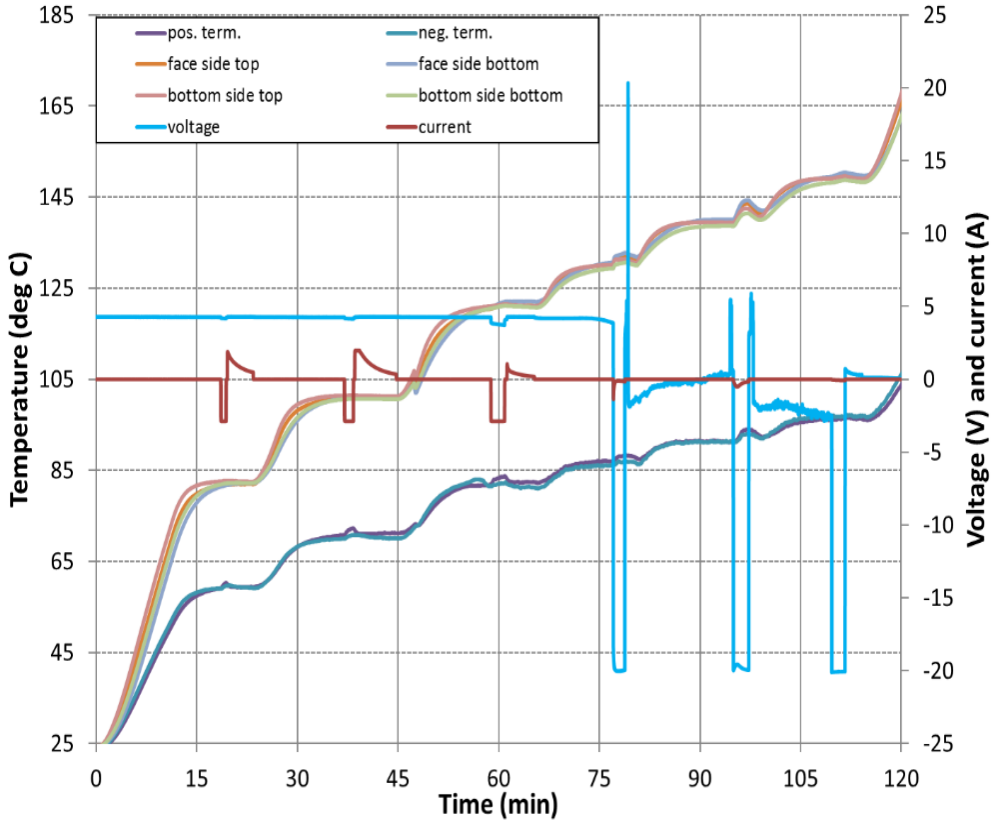
Can the energy be removed prior to cell failure?

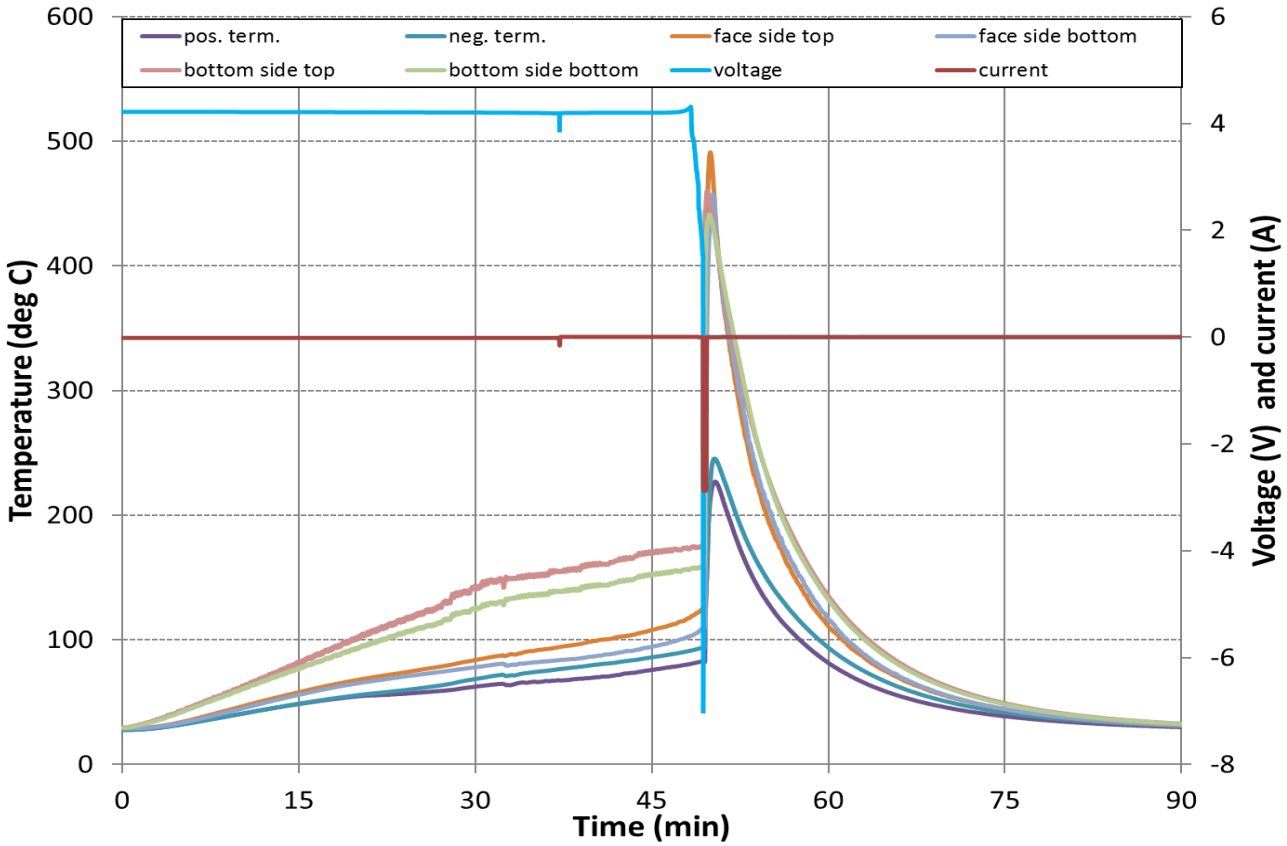
- **3 AH $LiCoO_2$ cells**
- **Heating applied through direct contact with hot surface**
- **Discharge attempted on cell as it approaches abusive temperatures**
- **Impact of changes to cell resistivity?**
- **Impact of separator shutdown?**

Discharge under abusive conditions



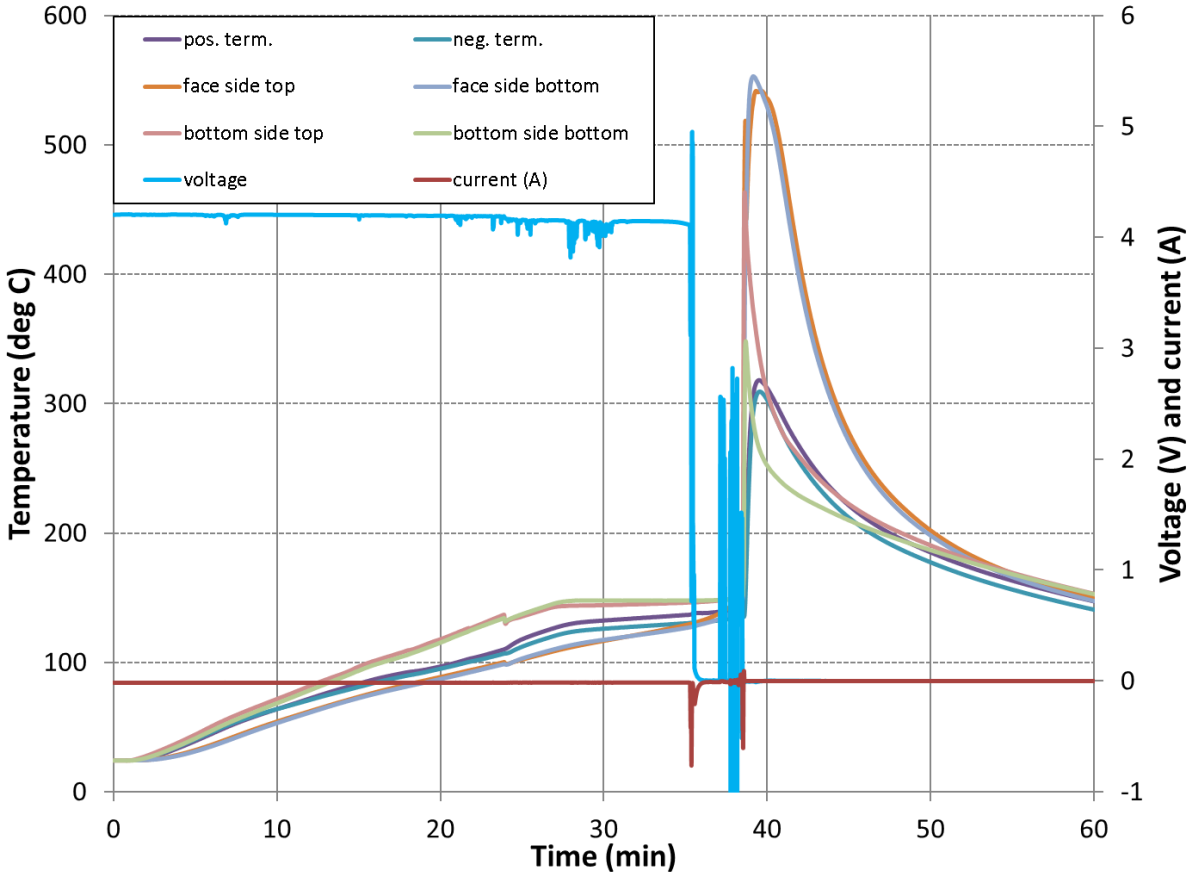
- **1C Discharge of 3 AH Li-Ion cell attempted at 20 C intervals with the first discharge occurring at 80 °C**
- **Cell discharges well at 90-100 °C and discharges with some polarization at 120 °C**
- **Cell is heavily polarized and does not discharge above 130 °C**

Discharge at 160 C



- **Cell heated to 160 °C and a 1C discharge attempted**
- **Discharge accelerates runaway process as cell goes into runaway almost immediately after initiating discharge**

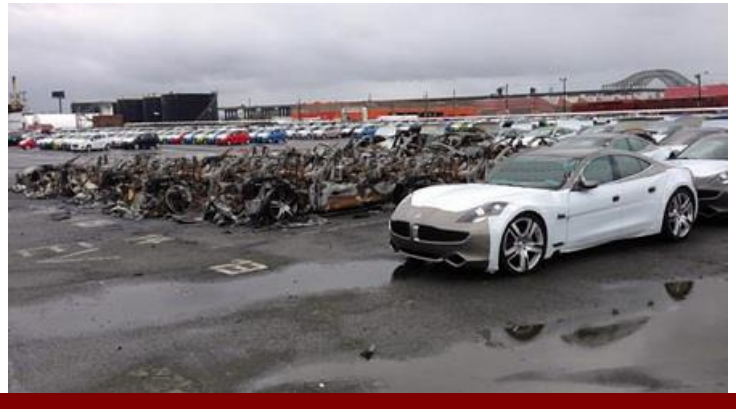
Discharge at 150C

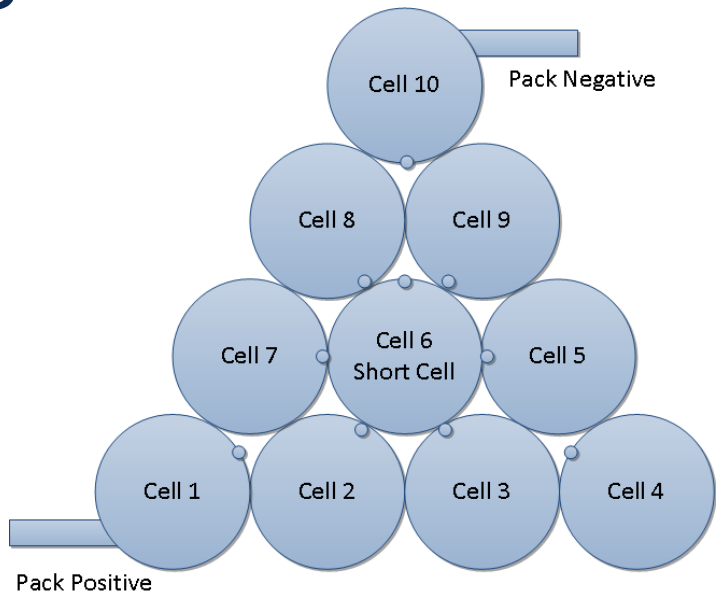


- **Cell heated to 150 °C and a 1C discharge attempted**
- **Discharge accelerates runaway process as cell goes into runaway almost immediately after initiating discharge**
- **Cell was relatively stable when compared to cell at 160 °C with little to no indication of self heating**

Battery Failure Propagation

- Simply, the propensity of the energetic failure of a single cell to cause widespread thermal runaway within a battery
- Most large battery systems are designed to withstand the loss of several cells from a performance standpoint
- A point failure becomes more serious if it can send nearby cells into thermal runaway
- Recent events (Fisker, Boeing) have had battery runaway events that engulfed the entire pack
- Provide previously collected data as well as new data to developers of battery propagation models





- Diagram showing cell and thermocouple locations
- Series and parallel constructions used, series pack wired in order from Cell 1 to cell 10
- Simple compared to a large battery system to understand general driving forces

Detailed procedure described in SAND2014-17053 “Propagation Testing Multi Cell Batteries” Available from Sandia

Battery Failure Propagation

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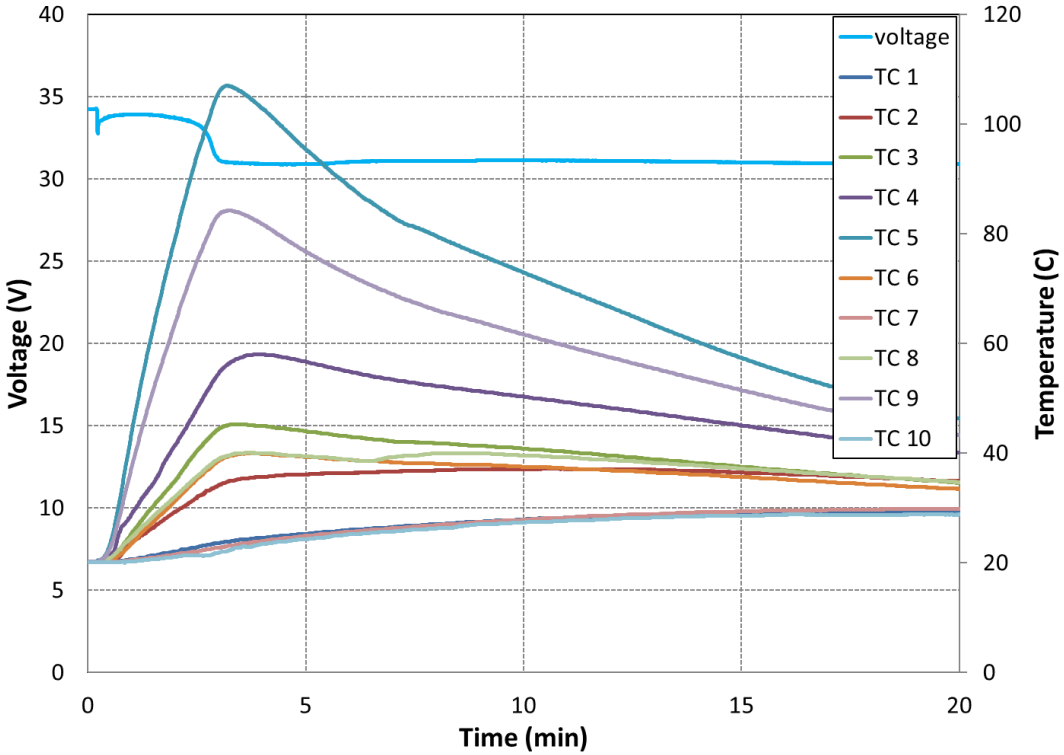
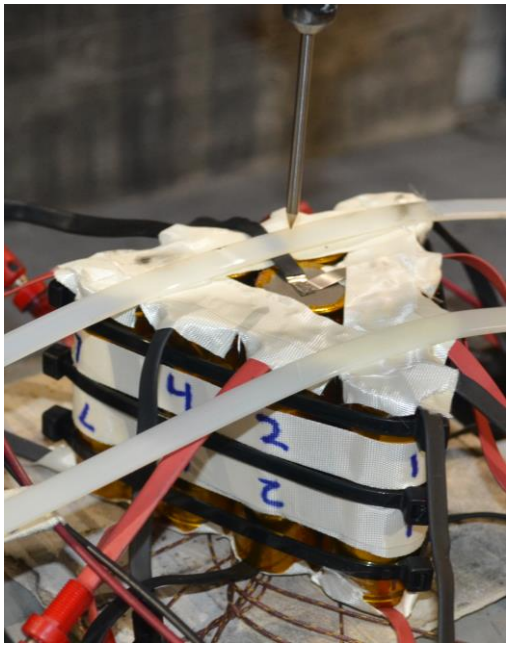
LFP 26650 cells – 10S1P





- **Pack constructed from 2.6 Ah LFP cells, failure initiated with nail penetration to central cell**
- **No cell to cell failure observed**
- **Heating rates observed similar to that for single cell**

What's the Impact?

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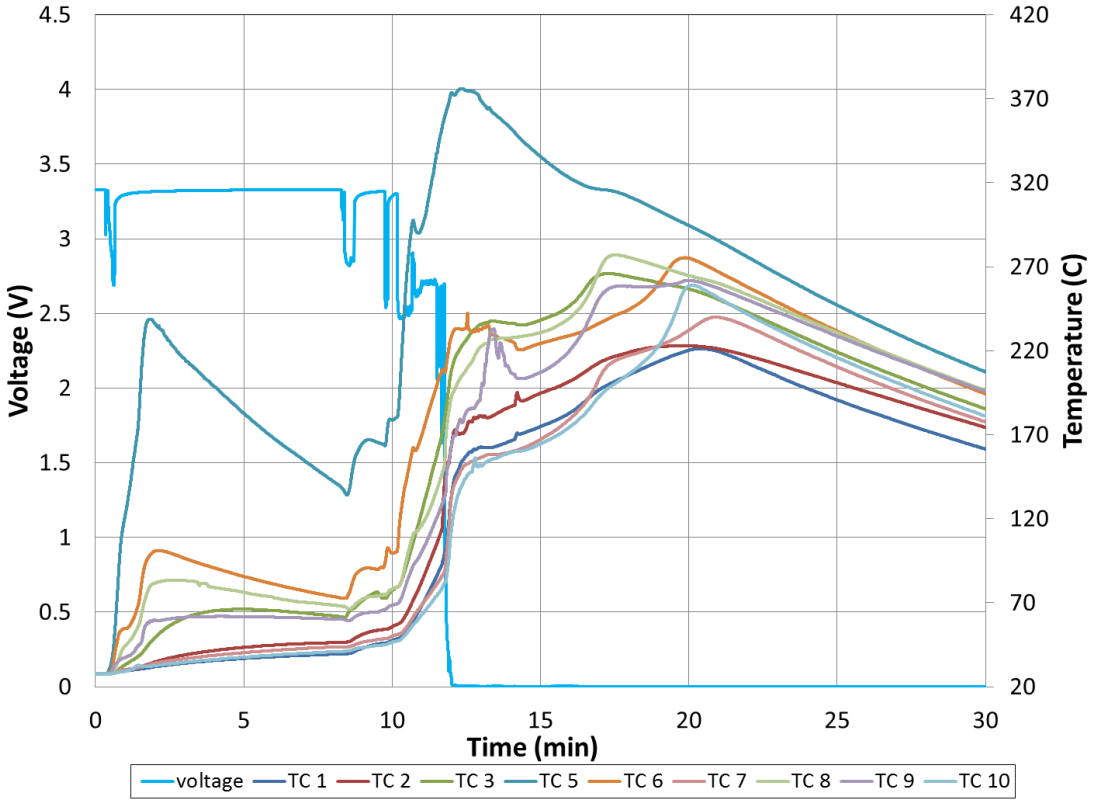
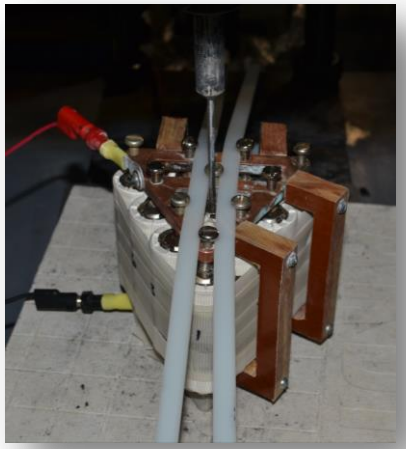
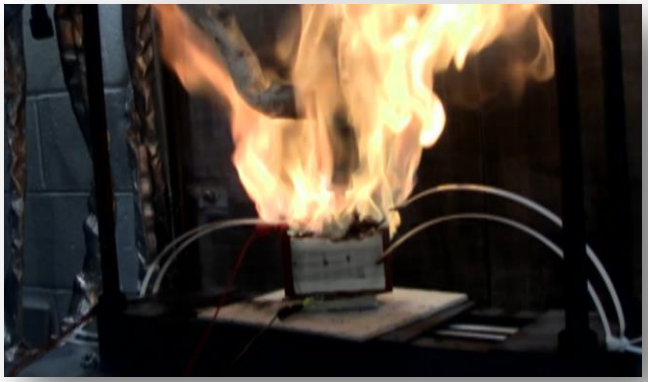
How a cell with low peak heating rates can have a catastrophic failure

LFP 26650 cells - 1S10P



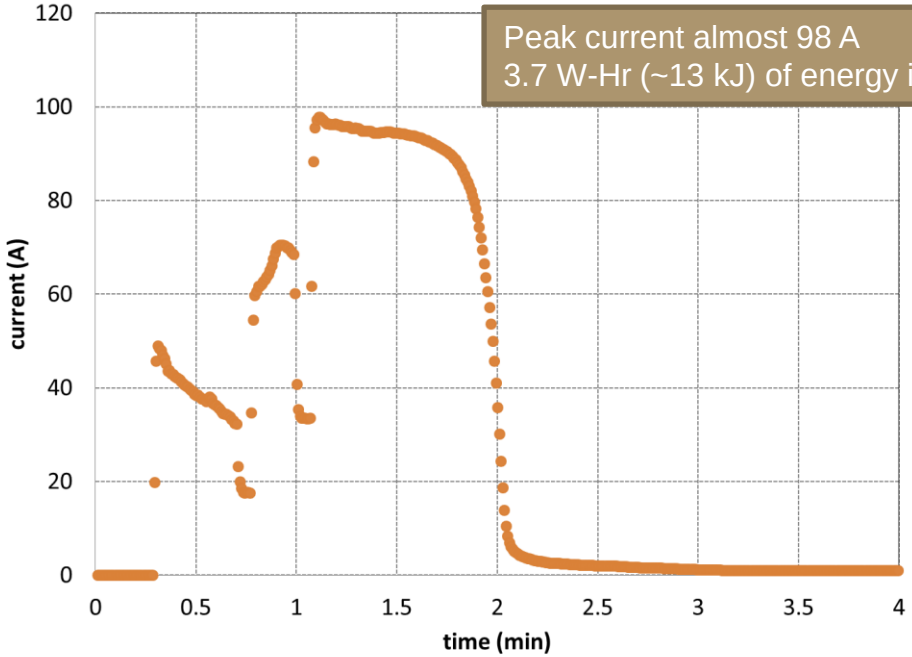


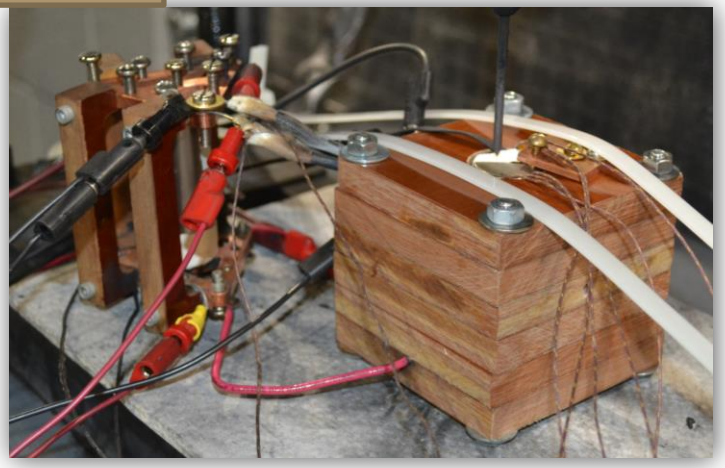


- **Pack constructed from 2.6 Ah LFP cells, failure initiated with nail penetration to central cell**
- **Complete propagation failure in LFP-26650 1S10P pack**
- **Significant increase in the severity of failure from a single cell – Single cell peak heating rates of ~105 W**

Internal shorts in parallel

Two cell parallel module – single cell short created with nail penetration
Short circuit current measured across constantan bridge wire of known resistance





- **A single cell delivered a peak of ~98A and 13 kJ of energy into the shorted cell in ~2 minutes**
- **This shows how the presence of stored energy within a system increases the potential for failure**
- **Could a runaway still occur with large numbers of low SOC cells or cells in well insulated conditions?**

Summary

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- **Li-Ion batteries are becoming more attractive to stationary systems due to the excellent performance of many Li-Ion chemistries, however several safety issues remain including:**
  - **How can a thermal runaway be arrested?**
  - **What is the impact of a single cell failure within a large system?**
  - **What impact will gasses produced during battery failure have on the surrounding environment?**
- **Discharging overheated cells was demonstrated to be achievable at moderate temperatures, however cell resistivity dramatically increases as cells approach thermal runaway.**
- **As the temperature approaches the onset of thermal runaway, application of a discharge was shown to accelerate the runaway process.**
- **Thermal propagation testing shows the potential for discharge currents to accelerate thermal runaway failure**
- **Discharge current testing shows a single cell contributing almost 100 A of current**

Contact Information

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